CR-152384

(NASA-CR-152384) PERFORMANCE CONSIDERATIONS IN LONG-TERM SPACEFLIGHT (Santa Clara Univ.) 93 p HC A05/MF A01 CSCL 05I

N81-18651

Unclas

G3/53 16362

(Preliminary Report)

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September, 1979

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Maintenance of skilled performance during extended spaceflight is of critical importance to both the health and safety of crew members and to the overall success of mission goals. An examination of long-term performance requirements is therefore a factor of immense importance to the planning of future missions. The following chapter gives coverage to a number of important factors related to this issue: definition of performance categories to be investigated, methods for assessing and predicting performance levels, in-flight factors which can affect performance, and factors pertinent to the maintenance of skilled performance.

Performance definitions

In long duration space flight, work is the significant factor determining lifestyle. It is both complicated and varied. A fundamental question to begin with is what are the work requirements of the astronaut and how can we conceptualize the astronaut within an integrated human-machine complex? Reduced to its most general form, the astronaut is responsible for the following tasks (1):

a. monitoring and control of the operation of onboard systems
b. control of spacecraft movement in performance of various dynamic operations (orientation, stabilization, approach, docking, orbital correction, descent from orbit, landing)
c. conduct of radiocommunication and television reporting

d. conduct of visual observations, conduct of scientific experiments and investigations

e. assembly and disassembly of individual units of the craft, performance of various operations outside the spacecraft

f. operation of special gear

g. carrying out onboard documentation

However simplified this listing may be, it does serve the purpose of emphasizing the complexity and diversity of work requirements imposed upon the astronaut. This point is further demonstrated by the fact that the complexity of missions to date has increased considerably at each stage of flight both in terms of the number of required tasks and by the engineering requirements the astronaut must master to successfully complete the mission goals. Table 1 issustrates the increased number of control panel and display characteristics which have developed across the various flights of the U. S. manned space program. As the number of mission requirements increases, the benefits of multi-trained crews with specific, but overlapping responsibilities increases. With the advent of the Space Shuttle Program, we see the first real instances of crew responsibilities in which specific division of team members received training and are responsible for specific mission tasks. Previous flights have relied much more on overlapping and multi-task crews in which everyone basically received similar training to execute specific tasks. Now we are faced with the additional complexity of monitoring and evaluating performance characteristics of astronaut-pilots, astronaut-scientists and eventually personnel in other categories of mission task allocation. These facts place investigators of performance capacity in a very difficult position, since the criteria

TABLE 5.—*Crew Control and Display Characteristics*

Device characteristic	Spacecraft							
	Mercury	Gemini	Apollo		Skylab			
			Command module	Lunar module	Command module	Orbital assembly module		
						Multiple docking adapter	Airlock	Orbital workshop
Panels	3	7	28	12	26	31	58	74
Work stations	1	2	5	2	5	3	4	8
Control elements (total)[1]	98	286	721	378	760	350	694	363
Circuit breakers	(20)[2]	107	264	160	256	19	307	214
Toggle switches	56	123	326	144	372	239	326	88
Pushbutton switches	8	20	13	7	15	12	0	0
Multiposition rotary switches	6	19	21	16	19	50	22	32
Continuous rotary switches	3	0	35	21	36	17	3	9
Mechanical devices	3	13	57	26	57	7	35	18
Unique devices[3]	2	4	5	4	5	6	1	2
Display elements (total)[1]	45	68	131	144	152	222	323	116
Circular meters	16	7	24	6	23	1	0	2
Linear meters	0	25	33	25	33	14	64	42
Digital readouts	3	14	18	13	19	20	1	18
Event indicators	19	16	47	96	68	182	258	50
Unique displays[4]	7	6	9	4	9	5	0	4
Inflight measurement points[1]	100	225	475	473	521	918	521	281
Telemetered	85	202	336	279	365	918	521	230
Displayed on board	53	75	280	214	289	167	129	30
Caution and warning	9	10	64	145	61	97	91	8
Input								
Analog signal	9	10	42	45	33	2	87	2
Discrete signal	0	0	22	100	28	95	4	6
Output	9	10	35	34	35	13	38	8

[1] Numbers for each program vary, depending on particular spacecraft.
[2] Fuses, not circuit breakers, used in Mercury.
[3] Three-axis hand controllers, computer keyboards, etc.
[4] Flight director attitude indicator, computer displays, entry monitor, cross points.

were:

- the principle that there would be redundant means available to accomplish all critical functions;
- the need to have available both on-board and ground data concerning the status of consumables;
- the need, with intermittent communications, to maintain a common time reference with the ground control system to control mission sequences and the retrofire maneuver, which initiates ballistic entry.

To save weight and power, attitude was displayed on a meter with three movements: a horizontal needle moving in the vertical plane for pitch and two vertical needles (one at the top and one at the bottom) moving horizontally to display yaw and roll. Attitude rates were displayed on separate movements arranged around the attitude indicator.

to evaluate performance must be diverse and therefore probably frequently contradictory. Attempts to define the performance evaluation criteria of operators in other work situations have been frought with problems. For the astronaut there are at least two basic differences from other operators which make this evaluation even more difficult. First, the astronaut works under unusual environ- ~~mental conditions~~ (isolation, confinement, weightlessness, etc.) and secondly, the operator functions frequently are not an end in themselves, but rather prerequisites for the conduct of scientific research, data collection and management, etc. As a result, comparison of the astronaut to operators under other conditions within business and industry is difficult at best. However, there are some universal similarities among all operator behaviors which do unite research from various areas of human factors, ergonomics, and other broad approaches to the study of human performance under complex and variable conditions. Several investigators (3, 4) have attempted to design a taxonomy of operator behaviors with varying degrees of success. One widely used listing comes from the work of Berlinger, Angell, and Shearer (4) as shown in Table 2. The purpose of such a scheme is to analyze what functions operators perform in a system as a basis for task analysis. For our purposes it gives a broad overview of the types of behavior performance measurement available and offers a beginning point for a discussion of the various approaches to performance assessment.

Methods For Assessing Performance

The assessment of performance under space flight conditions

[illegible] or Dimension
([illegible] Angell, and Shearer, 1964)

Processes	Activities	Specific Behaviors
1. Perceptual processes	1.1 Searching for and receiving information	1.1.1 Detects 1.1.2 Inspects 1.1.3 Observes 1.1.4 Reads 1.1.5 Receives 1.1.6 Scans 1.1.7 Surveys
	1.2 Identifying objects, actions, events	1.2.1 Discriminates 1.2.2 Identifies 1.2.3 Locates
2. Mediational processes	2.1 Information processing	2.1.1 Categorizes 2.1.2 Calculates 2.1.3 Codes 2.1.4 Computes 2.1.5 Interpolates 2.1.6 Itemizes 2.1.7 Tabulates 2.1.8 Translates
	2.2 Problem solving and decision-making	2.2.1 Analyzes 2.2.2 Calculates 2.2.3 Chooses 2.2.4 Compares 2.2.5 Computes 2.2.6 Estimates 2.2.7 Plans
3. Communication processes		3.1 Advises 3.2 Answers 3.3 Communicates 3.4 Directs 3.5 Indicates 3.6 Informs 3.7 Instructs 3.8 Requests 3.9 Transmits
4. Motor processes	4.1 Simple/Discrete	4.1.1 Activates 4.1.2 Closes 4.1.3 Connects 4.1.4 Disconnects 4.1.5 Joins 4.1.6 Moves 4.1.7 Presses 4.1.8 Sets
	4.2 Complex/Continuous	4.2.1 Adjusts 4.2.2 Aligns 4.2.3 Regulates 4.2.4 Synchronizes 4.2.5 Tracks

has been of scientific interest for at least two reasons. First, assessment has been needed to determine whether tasks conducted in space are executed via successful methods. For example, it is necessary to know whether astronauts are operating at an efficient level assuring safety and maximum probability of success. This requires having some estimate of how astronauts should be expected to operate under spaceflight conditions (perhaps through pre-flight simulations or inter-flight comparisons) and using this as a comparison of current in-flight performance levels in determining important mission procedures and goals (e.g., is the astronaut functioning adequately to attempt an extra-vehicular activity on a particular day?). In this particular case the assessment of performance is important in its own right as a measure of the current physiological and psychological capabilities of the crew. As we shall later see there are any number of factors which could affect a decrement in these conditions and possibly jeopardize the success of particular work endeavors. Another important aspect to the assessment of human performance under spaceflight conditions is the need to investigate how different spaceflight conditions (i.e., weightlessness, sleep deprivation (6), isolation and confinement, etc.) may affect performance. In this respect, performance levels can be thought of as a dependent variable against which to measure the relative effects of externally and internally imposed stressors upon the human operator. In this respect, we need to evaluate the use of methods which will be appropriately sensitive to these various potentially hazardous conditions and employ them in a way which allows us to investigate the method of action of these stressors. Thus in one case, knowing the level of performance is important in its own right in evaluating the health, safety, and capability of the

crew. On the other hand, the ability to measure changes in performance level serves as a valuable tool by adding to our understanding of how certain spaceflight conditions operate to influence human performance.

An understanding of performance assessment has also been important at different stages of mission planning. For example, performance assessment has been necessary prior to flight as a means of determining engineering and craft habitability constraints. An evaluation of human performance has lead to many guidelines in the layout and structural composition of spacecraft living and working quarters (5, 6) as well as instrument and control panel designs (7, 8). Performance assessment has been an integral part of the training of astronauts and the determination of their readiness for flight (9, 10, 11, 12). It has also been important in the selection of astronaut candidates as a basis for assessing spaceflight capability (13, 14, 15). Indeed, the measurement of performance has been one of the most important characteristics of our entire space program and intimately involved with all aspects of flight endeavor. Given the monumental importance of this fact, what are the present capabilities of our assessment tools and what are the factors requiring further development?

The range of assessment techniques can perhaps be best analyzed by conceptualizing them as a dimension varying in face validity with respect to actual mission conditions with single task minimally related techniques at one end and actual in-flight, operational condition techniques at the other. Intermediate to these two end points we could include multiple-task performance batteries and full-scale simulation operations. The following sections detail these general categories.

Single Task Assessment Techniques

The use of test batteries that consist of a number of appropriately selected or designed individual tasks has several advantages in studying the effects of various factors on performance. Generally, they are relatively low-cost, and performance on each individual instrument can be assessed rather exactly. Performance on ~~such~~ tasks ~~should~~ be generalizable to other conditions in which the tasks are employed with varying degrees of success depending upon the following qualities (15a, 16):

a. the availability of a taxonomy of the tasks that go to make up complex performances in operational systems

b. a task analysis of specific systems in terms of this taxonomy

c. appropriate weightings of the representational tasks in the test battery in accordance with their relations with the taxonomy and task analysis

While it is not possible to discuss all of the psychological tasks which are used to measure performance under varying conditions, it is possible to describe several broad categories of measurement outlined by Ruff (17), which are typically represented in varying degrees in different test batteries which have evolved. The following sections also provide examples of particular relevance to spaceflight conditions.

Perceptual Tests

Threshold. The intensity at which a stimulus can be perceived or different stimuli from the same dimension can be differentiated is an important aspect of performance measurement. In designing control displays of an audio or visual nature such information can

be useful in determining optimal design. Such measurements are also of value given the potential chances in visual acuity which may result during space flight (to be discussed later in this chapter).

Critical flicker fusion. This technique involves the measurement of the frequency at which a subject judges an intermittently flashing light as a steady one. This particular measurement has proven useful in detecting performance change during prolonged periods of stress (18) and under conditions favoring the development of anxiety (19, 20). Such tests have been useful in studies of long-term confinement and isolation and the effects of varying degrees of workload.

Perceptual speed. The degree to which subjects can process information and respond is of use in evaluating mental workload capabilities loading on attention, concentration, scanning, etc. Thurstone's random number task serves as an example. Here the subject is presented with two pages of numbers taken from a table of random numbers. The left-hand numbers of each row is circled. The subject's task is to cross out each digit in a row that is like the one circled in that row. Perceptual speed tasks are useful in assessing the operator's ability to rapidly scan and respond to visual information. Data from such tasks offer some generality to the monitoring and response to flight control panels in flight.

Perceptual retention. The task of the subject using these measures is to retain the maximum number of units from a series of stimuli. Typically, an auditory digit retention span task* is used such as the Digit Span subtest of the Wechsler Adult Intelligence Scale: lists of increasing length are read and the subject must repeat them both

forward and backward. Such tasks load on short-term memory processes and concentration and are useful in assessing sensitivity to stress.

Vigilance. Vigilance tasks typically require continuous monitoring of a display panel or other devices with periodic responses required. Mackworth's (21) technique involves a clock hand that usually moves in single steps, but occasionally gives a double jump. The subject responds only to the double jump. Vigilance tasks have frequently been used in research supported by NASA and the armed forces because of its similarities to the monitoring of radar and control equipment. Vigilance tasks are the standard techniques used in assessing the effects of monotonous task repetition and the effects of fatigue.

Discrimination. Discrimination tasks have involved any number of visual (e.g., color, brightness, etc.), auditory (e.g., pitch, tone, frequency, etc.), and even kinesthetic (e.g., textures, shape, etc) comparisons as a means of assessing acuity along those dimensions. Generally the subject's task is to compare one or more stimuli from the same dimension and make a same-different, more-less judgment. These tasks appear particularly useful in assessing sensory-perceptual alterations which may in turn be associated with performance decrements.

Motor Tests

Steadiness. Ruff mentions at least one test within this category. It entails the ability of a subject to hold a stylus in holes of decreasing diameter without touching the edges. Measure of body sway (22, 23) are also listed as indicators of steadiness. Such techniques are not routinely used in performance batteries, but can

prove useful in predicting performance in which either fine motor control or balance may be important factors.

Tracking. A frequently used technique in many performance studies is the use of the rotorary pursuit task. Here the subjects attempts to maintain constant contact between a stylus held in their hand and a click on a rotating turntable.. This instrument is commonly used to assess coordination and precision of motor behavior under conditions where speed is important.

Coordination. This task emphasizes speed and precision of motor behavior. One commonly used technique involves the Purdue Pegboard. Here the subject must complete serial assembly of small objects on a perforated board. Mirror drawing is another frequently used task. The subject must follow, with a pencil, a pathway of parallel lines in the shape of a six-pointed star. However, they can observe their progress only by looking at a mirror image of the tracing.

Perceptual-Motor Tests

Reaction time. Reaction time measures are among the most frequent in studies of performance as they are representational of the subject's alertness and capacity for reaction to potentially important situations. In simple reaction time experiments, subjects give a single response to a single stimulus. This situation can be expanded to require subjects to choose a proper stimulus before reacting. Complex reaction time has generally been found to be more sensitive to a variety of conditions.

Cognitive Tests

Problem solving. A wide range of tests can be said to fit this category, including arithmatic operations, problems in inductive and deductive logic, and tasks in which conclusions must be drawn from

visually or auditorally presented problems. Certainly, problem solving ability is one of the most important aspects of aerospace performance to be measured, but also one of the most elusive and least generalizable.

Concept formation. This category of tasks requires, in some way, that subjects search for common elements in a series of stimuli and form appropriate generalizations. An example from Ruff is the Wisconsin card-sorting task in which four stimulus cards and 64 response cards are presented to a subject. Each card bears one to four identical figures of a single color and the task of the subject is to sort them according to number, form, or color. After each response, they are told whether they are right or wrong with the concept rule changed after 10 consecutive correct responses. Performance on tasks similar to this have been shown to be adversely affected by factors which distract concentration such as noise, sleep loss, etc.

Conditioning and learning. This category represents a large number of tasks involving both classically and operantly conditioned behaviors as well as those involved in memory and retrieval processes. Subjects may be required to learn lists of nonsense syllables or to associate different responses to different verbal or non-verbal stimuli. Both the rate and amount of learning, as well as the retention of the learned material can be used as measures of performance, as affected by many physiological and psychological considerations.

Flexibility tests. The necessity of altering a previously learned set is a component of many tasks that measure primerily sensory or motor functions containing some cognitive functions. One such task is the Bourdon-Wiersma Stipple Test, in which subjects are

presented with horizontal rows of three-, four-, and five-dot clusters. Subjects are first required to place a horizontal line through five-dot clusters and a vertical line through four-dot clusters. After 20 lines, the instructions are reversed. Measurement of decrease in speed and increase in errors on the second and any subsequent instructions compared to the original condition yields an index of rigidity.

Cognitive-Information Processing Tests

Most recently, developments in the newly emerging and synthesizing fields of cognitive psychology and information processing have suggested new possibilities for conceptualizing and measuring such factors as memory, recognition, concept formation, etc. A number of the tasks are based on the use of reaction time as the dependent variable and revolve around measurement of classifications or rule learning models. While a review of these theories and models is beyond the scope of this chapter, work by Anderson (24), ~~Sole (25),~~ Lindsay and Norman (25), Atkinson and Schiffrin (26) and many others demonstrates that cognitive psychology-information processing models of intellectual performance does offer some significant advantages over previous measurement attempts. These studies suggest that specific cognitive components of performance (in contrast to motoric functions or overall task performance) can be isolated, providing the advantage of investigating them in their own right independent of interactions with other response output requirements. Furthermore, components exemplified by storage, encoding and retrieval processes, conceptual and episodic memory, short and long-term memory functions have been shown to be affected in previously unexpected ways by such factors as age (27, 28), drugs (29, 30), and mental retardation (31). Little if any research

has been documented to determine if such approaches are useful in assessing the potentially stress producing factors relevant to space flight. One study of bedrest stress conducted by Rothstein (32) will serve to clarify some of the performance tasks suggested by this new field. Rothstein employed four tasks to measure various aspects of the subjects' cognitive processing abilities as described below:

1. Item-Recognition. On each trial, the subject is presented with a memory set of between one and five consonants. The number of consonants in the set varies randomly from trial to trial. Following the memory set, the subject is presented with a test consonant. If this test stimulus was a member of the previously defined memory set, the subject is to make a "yes" response with her'his dominant hand; otherwise s/he is to make a "no" response with her'his non-dominant hand. The principal dependent variable of concern within the test battery is the slope of the best-fit linear function relating RT (Reaction Time) to the size of the memory set (i.e., the number of consonants in the memory set) for both "yes" and "no" responses. This is taken as a measure of memory retrieval processing time (33).

2. Visual Search. On each trial the subject is first given a target consonant. Following the target, the subject is presented a display set of between one and five consonants (test stimulus). If the target is a member of the test stimulus, the subject is to respond "yes", othersie s/he is to respond "no".

The principal dependendt variable within the test battery for this task is the slope of the best-fit linear function relating RT to display set size (number of consonants in the display set).

The interpretation of the slope parameter in this task represents the time taken to carry on a visual comparison between a representation of the display item and the memory representation of the target (for further details see references 34-36).

3. Category Recognition. On each trial the subject is presented with between one and three category names which s/he is to remember for the trial. Examples of category names are: FABRICS, and TOOLS. Following the memory set, the subject is presented with a potential exemplar (test stimulus) of one of the categories. For example, BASEBALL is a potential exemplar. If the potential exemplar is a member of one of the categories of the memory set (i.e., is in fact an exemploar of one of the categories), the subject is to respond "yes"; otherwise s/he is to respond "no". Test stimuli which are not members of one of the memory set categories (negative exemplars) are selected from categories not in the memory set. For example, if the memory set consisted of FABRICS, FRUITS, and TREES, then the following potential exemplars should properly be given a "yes" re-

ponse: ELM, APPLE, COTTON, WOOL, OAK. For the same memory set the following potential exemplars should properly be given a "no" response: BASEBALL, BRIDGE, HAMMER, PASTURE.

The slope of the best-fit linear function of RT from memory set size (number of categories in the memory set) is the dependent variable of primary concern within the battery. This slope represents category retrieval and comparison time (37).

4. Analogy Test. The test stimulus for each trial of the analogy test consists of the four terms of a verbal analogy. The analogy may either be true or false. An example of a true analogy is: SMALL:LARGE :: LIGHT:HEAVY. An example of a false analogy is: CHILD:ADULT :: COLT:BURRO. If the test analogy is ture, the subject is to respond "ture" by pressing the response button of his dominant hand; otherwise s/he is to respond "fale" with the other badn.

Preceding the test stimulus, the subject always sees a cue. The cue contains either zero, one, two, or three terms of the upcoming test analogy. The subject is to obtain as much information from the cue as s/he can before seeing the test stimulus. For example, in the condition of a 1 term cue, the subject would see: CHILD:. For the condition of a 2 term cue, the subject would see: CHILD:ADULT::. For the condition of a 3 term cue, the subject would see: CHILD:ADULT :: COLT:.

The analogy task, unlike the other tasks, of the battery, provides several diverse processing parameters. The differences in RTs between the zero and one cue conditions represents the time taken to encode a first analogy term and retrieve its meaning from semantic memory. (In general, the greater the number of terms in the cue, the faster will be the RT to the test stimulus.) The differences between RTs in the one cue and two cue conditions represent the time taken to retrieve the meaning of the second term and abstract a relationship between them. The difference in times between RTs in the two and three term conditions represent the time necessary to retrieve the meaning of the third term and to apply the relationship abstracted from the first two terms to it, to obtain an expected semantic content for the fourth term and to compare it to the meaning of the fourth term. The analogy task also offers a plethora of other processing parameters because the RT to complete processing of the cue can also be recorded and analyzed.

Unfortunately, due to methodological and procedural difficulties, Rothstein did not obtain any data which significantly discriminated between stressed bedrest subjects and controls. Nonetheless, this type of cognitive performance approach deserves further consideration as it represents an area of considerable heuristic and theoretical value. It is recommended that further studies of this type be implemented to ~~better assess~~ the validity, reliability, and usefulness of this new approach to the understanding of human cognition.

Comments On Single Task Assessment Techniques

While the single task assessment approach has been the method of choice in many laboratory studies (particularly those wishing to assess the effects of a single factor on a single aspect of performance) there are certainly several distinct disadvantages in the wholesale use of these techniques with regard to the astronaut operator. First, their is the issue of face validity, generally minimal in this case. We have no assurance that the factors assessed using these measures really have direct correlates to the actual in-flight performance of astronauts. Furthermore, it is questionable to what degree the results of such methods can be generalized to real operator conditions. We may also question the sensitivity of such single task instruments. The level at which some independent variable may affect a change in performance under these conditions may be considerably different than prevalent under operational conditions. These tasks are best used in settings where there is a specific question regarding the effect of some isolated variable upon a given aspect of performance.

They can be useful in at least indicating the direction in which more sophisticated techniques should be directed, but are probably of only minimal value when used individually, at least with respect to quantifying the probable levels of performance under genuine operational conditions.

At least two possibilities exist for enhancing the usefulness of ~~these measures. First, as Fleishman (38),~~ Parker (39) and others have pointed out, the maximum utility of these measures can be obtained through factor analytic analysis to determine which tests are pertinent to the features of the more complex operational task system. By selecting those tasks which have elements in common with the operational condition, the likelihood of obtaining relevant, generalizable data can be increased. Unfortunately, this still leaves the investigator with the problem of defining the specific task demand characteristics of the real work environment, no easy task itself.

Certainly, one important feature of the operational condition which is lacking in the use of those sequentially administered tests is the multi-task, concurrent demand, time-sharing requirements of the work environment. Some investigators have attempted to deal with this problem by combining two or more of these tests into a concurrent task situation. This does seem to enhance the sensitivity of the tests (40). For example, Finkelman and Glass (41) employed a dual-task methodology requiring simultaneous performance of a primary task (tracking) and a secondary task (recall). They found that unpredictable, uncontrollable noise produced decrement in the subsidiary task, but not in the primary. Likewise, Bell (42) found that using a tracking

task and a number processing subsidiary task, that noise and/or heat had detrimental effects on the subsidiary task, but not on primary task performance. The basic notion behind these findings is that subjects have only a limited capacity to process and respond to environmental information. Concurrent tasks can be performed adequately as long as sufficient ability exists for monitoring relevant information. However, when some stressful condition in the environment reduces the subject's ability to allocate resources to the tasks, the focus of effort will shift to the primary task to the decrement of the secondary task. Thus, performance may deteriorate on the less important task while remaining unchanged with the primary. Such findings represent more the norm in operational conditions. However, we are still faced with the issues of task face- and content validity.

In developing an assessment program for long-duration space travel the role of these single variable tests should probably be relegated to situations where only a specific environmental factor is being considered. They can probably be most helpful at lower level of the assessment process in reflecting conditions which can be more effectively researched using other techniques and thus giving direction to how higher level investigations should proceed. It is recommended that factor analytic studies be used to clarify which specific tasks or task features are most relevant to the operational condition in question. If used, some type of concurrent task system is probably desirable.

Multiple-Task Batteries

In efforts to minimize the disadvantages of the single task

methodology, various investigators have developed a battery approach to the study of performance. Alluisi (43) describes one such attempt which will serve as an example for our purposes. Alluisi describes this technique as a "synthetic work" arrangement rather than a "simulated work" system. The distinction lies in the fact that various tasks with potentially low face validity with respect to operational conditions are combined into a time-sharing work environment requiring performance durations more similar to those of operational conditions than the single-task approach, but not as directly comperable to the full simulation approach (to be discussed in a following section). The advantages of the synthetic work and multiple-task performance batteries lies in the potential for high content validity and relative exactness of measurement. Also, information relevant to a wider range of abilities can be acquired simultaneously, minimizing the difficulties of cross-experimentation confounding often cited as a problem when different subjects in different experiments perform different tasks.

The performance functions assessed in the multiple-task performance (MTP) battery reported by Alluisi are consistent with the broad categories outlined in a preceeding section. They include the following:

1) watchkeeping, vigilance, and attentive functions, including the monitoring of both static (discrete) and dynamic (continuous) processes
2) sensory-perceptual functions, including the discrimination and identification of signals
3) memory functions, both short-and long-term
4) communication functions, including the reception and transmission of information
5) intellectual functions, including information processing, decision making, problem soliving, and nonverbal mediation
6) perceptual-motor functions, especially to the extent that special skills such as aiming, tracking, swimming, driving, typing, and similar motor skills are necessary to the operation of the system
7) procedural functions that include such things are interpersonal coordination, cooperation, and organization.

These seven areas are represented either directly or indirectly in the sex tasks which compose the MTP battery. Individual tests include the following: 1) arithmetic computations, auditory vigilance, code-lock solving, probability monitoring, target-identifications, and warning-lights monitoring. While a range of flexible programming sequences are available to permit different degrees of workload demands, duration of testing, etc., an example of one measurement sequence is shown in Table 3 below as discussed by Adams, Levine, and Chiles (44). The MTP battery outlined by Alluisi has been used to investigate a wide range of variables of potential impact to the crew of space crafts: work-rest cycles, circadian rhythm desynchronosis, sleep loss, confinement, etc. (45, 46, 47, 48) and can be potentially extended to others. This particular approach to performance assessment would seem to be most useful in the selection and training of astronauts. It is less expensive than full scale simulation systems and permits more than a single individual to be measured at a given time. It yields a maximum of information regarding the subject's performance capabilities on several psychophysiological dimensions and can be used to investigate a range of environmental conditions. However, there is still a lack of face validity and direct comparisons to operational conditions are not entirely justifiable. The actual training of spacc flight crews will necessitate the development of simulators, the only real condition permitting accurate face validity. This approach is described in the following section.

Partial and Full-Scale Simulation

Full-scale, integrated, mission simulation provides the

with the perform- et al., 1962.)

hat requires an de function and

ong the studies have been used, yed is shown in e period so that eping tasks all of only part of the be low, interme- oing tasks are pre- h two (or more) of

rformance battery), data collection was influenced by ituation to which ather than individ- o be performed 24 days or longer, and trically restrictive. s designed to be a e.

Certain changes were made ... of the data obtained in the study. Five tasks were retained—three of the watchkeeping tasks (auditory vigilance, probability and warning-lights monitoring), and two of the active tasks (arithmetic computations and pattern discriminations). The tasks that were retained had demonstrated impressively high reliabilities, and they imposed relatively minor training requirements. The performance battery appeared to provide measures of essentially orthogonal functions, and it was capable of being programmed in numerous ways to make possible the study of a broad range of operator work loads (Adams *et al.*, 1959). The presentation of these tasks was integrated into a 2-hr work period similar to that which was given earlier in Table I; probability monitoring was not presented during the first and last 15-min intervals of the 2-hr period, arithmetic computations continued for an additional 15 min, code-lock solving did not occur at all, and pattern discriminations (instead of target identifications) began 15 min earlier than indicated for target identifications and continued for 45 min. The important thing to note is that time-shared performances were still required during each 2-hr performance period.

Table I

TYPICAL 2-HOUR PROGRAM FOR MULTIPLE-TASK PERFORMANCE*

Task	Minutes 000 015 030 045 060 075 090 105 120
	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Auditory vigilance	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Probability monitoring	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Warning lights	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
Arithmetic computations	xxxxxxxxxx
Code-lock solving	xxxxxxxxxxxxxxxxxxxx
Target identification	xxxxxxxxxx

*Each x represents 3 min; so 15 min is represented by xxxxx.

highest degree of fidelity possible in the simulation of true operational conditions. It is particularly important in space mission design because unlike other training settings, there is little opportunity for a graduated series of practice efforts under true operational conditions before the mission actually takes place. Crews for space missions must be completely trained and highly proficient in their tasks before the flight. As a result, it is imperative that high fidelity systems, both partial and complete, be available for training on specific and more integrated aspects of the mission. The use of simulator systems has been an integral part of our manned space effort to date. Beginning with the Mercury Program (49, 50) dependence upon high fidelity simulation programs has been a chief source of information for man-machine design factors, training experience, and total system check-outs. As the complexity of crafts and missions increased through the Gemini program (51, 52) the need for simulator training proved essential. The Gemini Program demonstrated that precise flightcrew response during space travel was contingent upon the fidelity of simulation training received pre-flight. The Apollo Program was even more dependent upon flight simulation systems (53, 54) as again, the complexity of mission tasks and craft design increased. While there is no doubt that simulation studies were particularly useful during these early missions, as well as the later Skylab missions and preparations for Space Shuttle flights, they have been used more often than not to assess performance of the entire man-machine complex, rather than to assess human performance in a given system. There are exceptions however, in which extremely useful performance data has been obtained (55). A second and more critical factor is our lack of understanding of how to measure sustained complex performance. This criterion factor is among the most difficult,

yet important unanswered questions relevant to all complex work conditions (56). Given that we don't really know how to effectively measure sustained performance under operational conditions, simulation studies in and of themselves do not provide any data about how the astronaut actually fares under real space flight conditions. For this, we would need actual in-flight data which could then be compared to pre-flight simulation (baseline) data. Such an approach is discussed in the next section.

In-Flight Performance

Prior to the Skylab missions, little quantitative data on human performance under space flight conditions was available. There was not a great variety in the types of manual tasks required and little if any detailed measurement systems. Training regimes pre-flight were not particularly helpful in serving as statistical, asymptotic baseline levels. Furthermore, little data was available through published sources indicating the degree and types of errors that occured during the missions. During Apollo 15 and 16 and with the advent of Skylab, a major source of in-flight data became available through the use of time-motion studies (57, 58, 59). Skylab missions 2, 3, 4 video and auditory recordings were used to measure the amount of time required to complete various tasks. Comparable baseline data had been collected pre-flight to use in comparison. A variety of tasks was selected for assessment, but were limited to those that were rather standardized, repetitive maneuvers which would satisfy replication and conformity conditions. Each of these tasks were subdivided into the components required to complete the maneuvers. Analyses were conducted to determine the degree of performance decrement (amount of time required

in-flight versus pre-flight) and the point at which work efficiency was restored to baseline (pre-flight) levels. Table 4 displays the number of measured task elements performed during trial 1 in-flight at a rate comparable to the last pre-flight trial. Note that during all missions the number of comparably performed elements is lower than the number performed less efficiently. Table 5 presents comparable data for in-flight trials 1 and 2 combined. Note that by the second trial approximately 50 percent of all elements were beginning to be performed at a rate comparable to pre-flight conditions. While this data is helpful it is somewhat more complicated than it appears based on the fact that different tasks were performed on different days of the missions. Thus, some of the tasks were not repeated a second time (second trial) for as much as 11 days after the mission began. Given that subjective adaptation to weightlessness, and flight conditions seems to require 7 to 10 days, the actual conditions under which the crews performed their various tasks was probably substantially different on different days (and thus different trials). These results provide little if any insight into the types of errors made or the specific conditions which may have affected them (i.e., weightlessness per se, motion sickness, sleep deprivation, etc.). At least in the case of space motion sickness we can infer performance decrements based on daily work efficiency ratio as described by Garriott and Doerre (60). They computed efficiency based on the number of hours worked divided by the number of hours available to work. Results for Skylab missions 2, 3, 4 are shown in Figure 1 below. Using figures from normal working conditions on earth, awake time (16 hours) can be divided into 8 hours of "useful" work and

namely, the number of instances that time for the first in-flight trial was greater than that for the last preflight trial, and vice versa. The results are found in table 16–I. Thus, in the Skylab 2 mission,

TABLE 16–I.—*In-flight (I) Element Time (First Trial) Compared with Corresponding Preflight (P) Element Time (Last Trial) for the Skylab Missions*

Skylab mission	I>P		P>I		*Percent* (I>P)	
2	95	[1] (36)	44	(19)	68	(64)
3	61	(32)	52	(21)	54	(60)
4	94	(37)	66	(32)	58	(54)
TOTAL	250	(105)	162	(72)	61	(59)

[1] Figures in parenthesis refer to Basic Elements only.

95 elements took longer to complete in-flight than preflight. For 44 elements, the situation was reversed. In 68 percent of the cases, then, the first inflight trial took longer than the last preflight trial.

Although the effect was not so pronounced for the remaining two missions, the results were consistent. When the results of the three missions were combined, it was observed that 61 percent of the first in-flight trials took longer than the corresponding last preflight trials.

Data in parentheses refer to Basic Elements. As shown in the table, percentages based on the basic elements appeared more consistent from mission to mission while summary results based on all three missions yielded almost identical percentages (59 versus 61).

second in-flight trial, were done as rapidly as they were on the last preflight trial. For example, by the end of trial 2, 44 of the 86 elements on Skylab 2 were completed within the time taken on the last preflight trial.

From an overall viewpoint, the results for the three missions were fairly consistent. When the elements were totaled across the three missions, exactly half of the elements returned to preflight baseline (last preflight trial) by the end of the second trial.

TABLE 16–III.—*Number of Elements Performed In-flight (First or Second Trial) as Speedily as on Last Preflight Trial*

Skylab mission	*In-flight time > last preflight*	*In-flight time < last preflight*	*Percent* (I>P)
2	44	42	51
3	46	53	46
4	51	46	53
TOTAL	141	141	50

TABLE 17-I.—*Activation Man-Hours: Accomplished and Available*

Skylab mission	Mission day 1			Mission day 2		
	Accomplished	Available	Efficiency ratio	Accomplished	Available	Efficiency ratio
2				24.4	46.5	0.52
3	12.3	22.5	0.55	22.0	54.0	0.41
4				27.5	51.0	0.54

Skylab mission	Mission day 3			Mission day 4		
	Accomplished	Available	Efficiency ratio	Accomplished	Available	Efficiency ratio
2	27.7	51.0	0.54	26.3	48.0	0.55
3	22.3	40.5	0.55			
4	23.8	52.5	0.45	10.3	18.0	0.57

8 hours of "overhead" or housekeeping function. Thus a ratio of .50 indicates a normal work day (8:8+8=.50) on earth. From Figure 1 we see that during day 2 of Skylab 3 and day three of Skylab 4 the work efficiency ratio is well below normal. This decrease appears to be due to the restrictive problem of space sickness prevalent on those particular days. Again, unfortunately these results do not tell us anything about error rate or type due specifically to motion sickness. We can make some inferences about the most probable types of errors based on the time-motion studies. Analyzing performance times for maneuvers requiring fine, medium, or gross movements indicate that while all three were initially affected, fine motor movements demonstrated the greatest decrement. These results are shown in Table 6. Similar results have been reported for extra-vehicular activities as well (59). However, this still does not provide error rate and data type.

While time-motion analyses and efficiency ratios are useful tools in providing us with global indices of performance they do not answer certain specific questions of importance. It is not possible to determine what specific factors may have influenced decrements in these measures. Also, of perhaps greater importance, their post-hoc nature does not give us specific information about the status of the crew at the time the tasks are performed. An additional limitation is that these measures focus more on work output, they permit few inferences about the quality of work or the types of errors made. One final point, is that in the case of the time-motion studies emphasis is focused on standardized, repetitive tasks. We have no information on categories outside this range which may require greater problem solving or general cognitive abilities.

The elements were also categorized into three classes representing tasks requiring fine, medium, and gross motor dexterity. Because of the consistency of results from mission to mission, the data were combined across the three missions. The basic comparisons, first in-flight versus last preflight, were thus available for the three types of motor activity involved in task performance. These are presented in table 16–II.

TABLE 16–II.—*Comparison of Preflight and In-flight Performance Times for Elements Categorized into Fine, Medium, and Gross Motor Activity Classes*

Type of motor activity involved	*First in-flight > last preflight*	*First in-flight < last preflight*	*Percent* (I>P)
Fine	83	49	63
Medium	122	81	60
Gross	39	30	57

Although the first in-flight trial generally took longer than the last preflight trial, a result established in the previous analyses, the percent increase was most pronounced for fine motor activity, less so for medium and least for gross motor activity. The percentage differences are small and insignificant but the systematic decrement is important. Such a decrement would reinforce the debriefing comments of the astronauts who reported that the control of small objects caused more difficulty than the control of larger masses.

Return to Preflight Baseline.—It has been noted that the first in-flight trial generally took longer to perform than the last preflight trial of the same task. The question arose as to how long it would take to adapt to the Skylab work environment, or more specifically, how many trials it would take before an in-flight task was done as speedily as it was on the last preflight trial. The criterion of equivalent performance was taken to be that particular trial at which half or 50 percent of the task elements were done as speedily as in the last preflight performance.

The sources for this analysis were the activities involved in experiment M092 (Prerun and Postrun, Subject and Observer), Experiment S073, and Suit Donning and Doffing. Table 16–III presents the number of activities which, at first or

Comments on Performance Measures

The range of performance measures spanning the dimension of face validity have each contributed to our understanding of the astronaut in space. Each has advantages and disadvantages. However, certain problems seem to dictate our greatest focus for future research efforts. The first is defining criterion by which to measure performance. Until we can adequately determine how performance should be measured under actual operational conditions, it is difficult to see how ground-based systems can be of any real help with respect to detection and prediction of conditions which may deter optimal performance. Certainly, more effort is required to ensure systematic, quantitative and qualitative data on performance in flight. Combined with the criterion problem is the issue of task predictive validity under ground-based conditions. For research purposes, emphasis should be placed more on predictive rather than face validity, although for selection and training purposes the reverse is true. Continual emphasis on how physiological indices relate to performance aspects of behavior is necessary. Both behavioral and biomedical measures are needed to determine flight crew status at any one point as a means of monitoring and detecting potentially disruptive conditions (i.e., fatigue, stress).

Given this discussion of the measures available to assess human performance, let us proceed to the issue of what conditions which may adversely affect performance. Recall that the need for performance assessment is both to monitor the health and safety of the crew, but also for use as a tool to investigate what effects specific conditions in space can and do affect performance. Our understanding of

these is paramount in the planning of future long-term missions if we are going to be able to sustain crew performance, physiological and psychological health, and successfully complete mission goals.

Factors Adversely Affecting Performance

Weightlessness

Work capacity. While weightlessness produces many physiological alterations as outlined in a previous chapter, little if any information is availabe on how this translates into changes in performance under operational conditions. A few of them are discussed below, but this section focuses on the effects of weightlessness per se. At least two important factors are directly affected by zero g. The first of these concerns the problem of motor movements. As indicated earlier, fine motor movements are adversely affected during both intravehicular (IVA) and extravehicular activities (EVA). This decrement in dexterity can pose potential problems for the manipulation of control panels, sensitive scientific experimental apparata, etc. until some degree of adaptation is achieved. Given the ever increasing complexity of equipment (as pointed out by Table 1) the chances of errors is increased by this problem. Equipment designers must be sensitive to this issue, ensuring that switches are easily manipulated, do not require unnecessarily delicate tuning, and are positioned in a fashion which allows maximum individual access without the chance of altering one while attempting to manipulate another. It may be desirable to schedule specific inflight exercises to enhance dexterity prior to the execution of important maneuvers requiring this capability.

Also related to changes in potential accuracy and amount of work

output is the greater amount of metabolic costs required to conduct work in space as demonstrated in extravehicular activities. Studies demonstrate that the metabolism rates during EVA can be potentially dramatic as in the early Gemini flights if certain considerations are not made. Fatigue and exhaustion cancelled some EVA in early missions. This was due to the unique character of working in space where difficulties are encountered in producing reactions to actions once momentum has been imparted and the problems of maintaining position in the absence of traction. Problems have also been encountered in moving within a pressurized space suit. Many of these difficulties have been resolved through realistically simulated weightlessness training (water immersion techniques) and changes in equipment designs. Also, specific training is used to teach crew members to monitor muscle groups and to remain maximally relaxed. While these efforts have proven successful as indicated by the number of subsequently completed missions, the metabolic costs of EVA as reported on later missions such as Skylab (61) does still warrant consideration in planning the amount and scheduling of such activities.

<u>Space motion sickness</u>. Space motion sickness as previously discussed poses a definite problem to astronaut performance levels at least in the early phases of a mission, or until acclimation has been accomplished in each sector of the craft. This problem has been described in more detail in a previous chapter, but for present purposes let us focus on how this byproduct of weightlessness affects performance rather than physiology.

There have been multiple cases of space sickness experienced by astronauts and cosmonauts during space flights. To give a few examples of the more severe episodes we might first focus on astronaut Russell

available on the various physiological effects which result from exposure to weightlessness, very little of this has been directly related to specific performance aspects of spaceflight. This has been true for many reasons, chief among them, that flight schedules have not focused on obtaining specific performance data. Monitoring systems have been somewhat inadequate to the task. Perhaps the introduction of performance tasks specifically designed to be sensitive to the influence of various enviornmental (noise, Temperature, etc.) and physiological (sleep deprivation, mental workload, etc.) conditions would be of value in more effectively assessing what is so difficult to infer from changes in complex, overlearned operator functions. The work of Frazier (73) and co-workers in investigating various operant conditioning techniques as measures of responses to critical stress illustrates one such approach. Further work in this area is certainly warranted.

Habitability

While many issues concerning the factors necessary to ensure optimal habitability of space crafts for long-term flight have been discussed in another chapter, there are certainly aspects of this domain shich relate to the maintenance of performance. The environmental conditions of the ship can play a major role in affecting performance as outlined in the sections below.

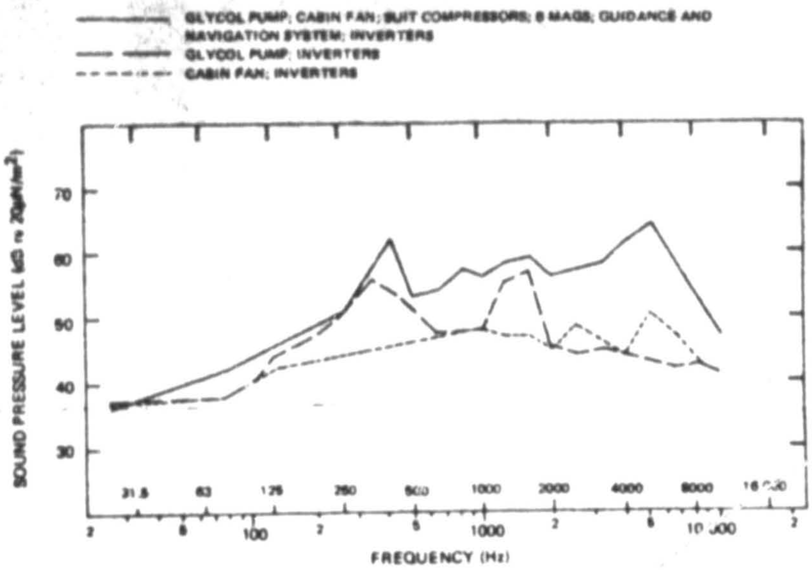
put Noise level. Noise levels during space travel have been considered in great detail both as they relate to psychological and physiological aspects of performance. At least two broad levels of noise must be considered as potential hazards to maximizing performance. The first entails high intensity blasts associated with thruster firing, the other with continous and intermittent background noise. In the former case, concern focuses around the possibility of

temporary threshold shifts (TTS) in which auditory perception is momentarily decreased due to high intensity sound blasts. Such incidents have implications for the transmission and receival of auditory communications. The probability of performance errors due to misunderstandings of auditory instructions, commands, etc. are certainly increased during these periods. This suggests the need for more reliance upon other sensory spheres (such as vision) for the communication of information to the astronaut during these instances. While it appears that this issue has been satisfactorily resolved during missions to date, it is a consideration which must be continued to be appreciated. As greater amounts of thrust are required to launch and power the larger vehicles required for future long-duration missions, the issue of acceptable blast intensity noise levels will probably become even more critical. Continued research in this area is needed to better assess noise tolerance levels and specific constraints upon communication systems as they relate to overall operator performance.

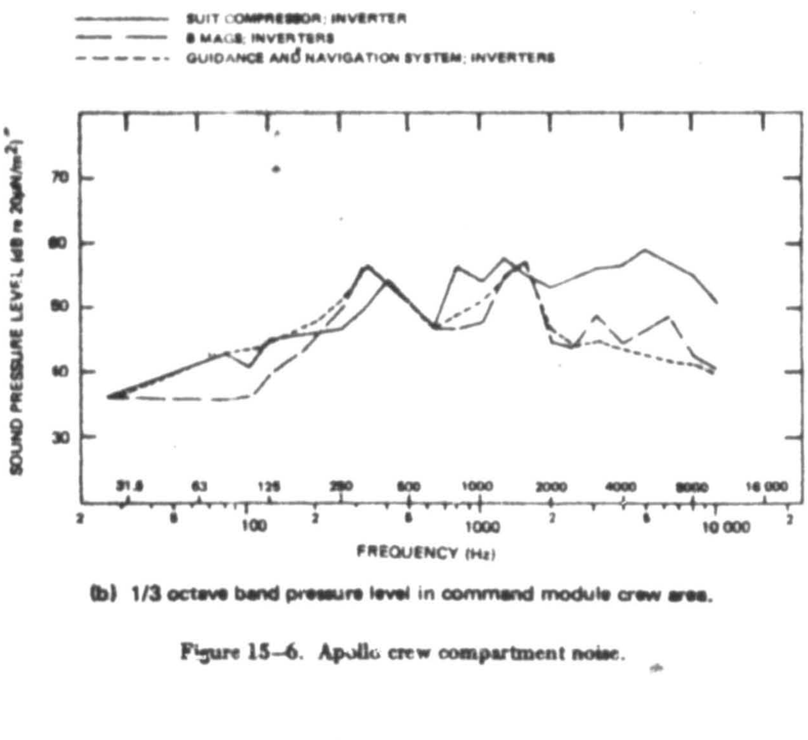
Perhaps more important to our present concern is the issue of whether continous or intermittent background noise during missions poses any difficulties to the performance of critical tasks. Aside from the issue of effects upon auditory perception, such as constraints upon speech communication, there are several issues concerning lowered efficiency of work which does not involve conversation.

Noise can be said to have two distinct effects upon behavior. First, it produces distraction and therefore lowered performance, particularly in tasks that require concentrated attention such as instrument monitoring, cognitive processing, etc. In this respect, intermittent noise appears to be the greatest offender (74, 75, 76).

Each occasion that the noise occurs in it may produce distractions and thus performance decrements. With continous noise the operator may partially adapt if the sound is not to great. However, adaptation does not occur as readily with intermittent exposure. Noise can also produce alterations in arousal level which can in turn affect performance. Unfortunately, no consistent effects of noise on cognitive and sensorimotor performance has been demonstrated. Generally, increase in arousal due to noise can be beneficial during performance of routine, monotonous tasks during which momentary motivation may decline. However, in the case of heavily loaded cognitive tasks (such as problem solving) increases in arousal level may produce concentration decrements in turn reducing performance. Kryter (77) in his review of work in this field over the past 10 years concludes that noise will not "directly interfere with mental or motor performance" when present below levels of about 27 dBA. It may have potentially beneficial effects due to arousal and isolation from distraction when present at about 27 to 67 dBA, and may have possibly detrimental effects above 67 dBA due to overarousal, aversion, and distraction from the task. Questions remain unanswered as to whether such effects have influenced space crews to date. Certainly, there have been complaints of background noise hindering sleep (78, 79). This at least suggests that such noises may add to the already large number of potentially adverse conditions affecting the performance of space crews. However, based on Kryter's analysis we find that noise levels currently recorded during flight are within the acceptable range. Figures 2 and 3 illustrate noise levels for various equipment tested in preparation for Apollo non-powered flight (80). As the length of flight increases and thus the length of exposure to these various noise levels, our understanding of how noise does affect performance will become increasingly important.



(a) 1/3 octave band pressure level in command module crew area.



(b) 1/3 octave band pressure level in command module crew area.

Figure 15–6. Apollo crew compartment noise.

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(84, 85). Whole-body vibration, particularly in the 4-10 Hz range decreases effective speech production and intelligibility (86, 87). Finally, low frequency vibration can degrade performance centrally, acting in a non-specific manner as a distracting and fatiguing agent (83). This last condition may prove to be the most important consideration for extended flight. Low level, but continous vibration can deplete the operator of reserves necessary to sustain maximal performance during critical periods. With all of the potentially annoying aspects of extended space travel, every effort must be made to minimize even the factors of seemingly modest consequences. It is often the synergistic combination of these factors which retards performance, despite the fact that no one variable alone produces noticeable effects. This point will be discussed in a later section.

Considerable data has been generated in attempts to investigate the above range of effects due to vibration. Some of the most directly relevant data has been obtained from flight tests and flight simulations. Gierke, Nixon, and Guignard (88) have summarized these well in their review of vibrational effects. They point out that vibration at frequencies below 2 Hz are associated by aircrew with:

a. discomfort and progressive fatigue
b. increased effort by pilots to avoid or correct inadvertent control movements
c. difficulty in using navigation instruments
d. difficulty in interpreting flight instrument information
e. disorientation, occassionally

Higher frequency (2-10 Hz) vibrations are associated with:

a. difficulty in reading instruments or carrying out other tasks calling for final visual discrimination (e.g., visual search, reading CRT display)
b. interference with some manipulative tasks (e.g., writing, setting cursors on handheld navigation aids)
c. general discomfort and progressively worsening fatigue on long missions

Given this range of effects and our previous experiences with the problems of vibration during short-term spaceflight it is clear that every effort should be made to reduce vibration levels during extended long-term flight, particularly during the long, but crucial cruise phase.

Temperature. Variations in temperature has been demonstrated to affect human performance in diverse ways. In general, performance begins to deteriorate in any circumstance where heat reaches about 75% of the physiological-tolerance limit (89). Several studies (90, 91) have demonstrated decrements in cognitive and psychomotor performance at temperatures at or above approximately 85°F with accuracy tending to decrease as temperature continues to increase. While there are a multitude of qualifiers to these results (humidity levels, stored body heat, water loss, vapor pressure, etc.) it is clear that increased temperature can adversely affect performance. Furthermore, the duration of exposure can influence performance decrements due to increased heat. For example, Figure 4 taken from the work of Roth (89)

Performance Under Heat Stress. Performance begins to deteriorate in any given condition at about 75 percent of the physiological tolerance limit. Although highly motivated individuals may be capable of exceeding normally established performance and tolerance limits (Teichner, 1961), excessive penalties in recovery time may be required if normal limits are exceeded. Even though no other stresses are anticipated or evident, it is suggested that 75 percent of the average tolerance limit level not be exceeded until the significance of deconditioning that occurs during space flight is better understood. Figures 3-23 and 3-24 reflect performance decrements as a function of ambient and effective temperature.

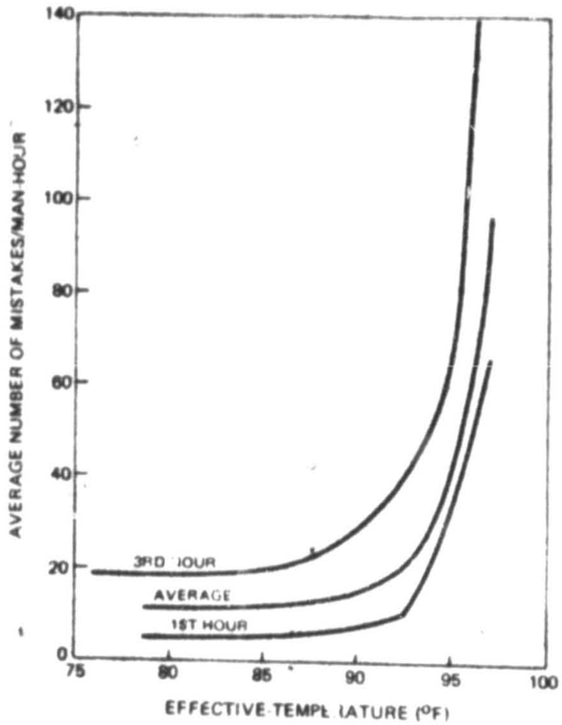

Figure 3–23. Combined performance averages for 11 wireless telegraph operators under conditions of extreme heat. (Roth, 1968)

Table 3-11 summarizes the physiological response increases and decreases in environmental temperature (Spector, 1956). The debilitating effects of heat have received much attention (Lind, 1963).

Table 3-12 classifies the symptoms to be expected from the debilitating effects of heat.

illustrates decrements in operator performance at various temperature levels and exposure durations. Note that as either temperature or length of exposure increases performance errors tend to increase. The types of task performed appear to be differentially sensitive to heat strain as indicated by Figure 5. Note that cognitive tasks appear to be the most adversely affected, presumably because of changes in arousal level. While heavy psychomotor performance work is heat affected similar results have been obtained by other investigators as well (92). However, tolerance to heat strain for varying exposure durations appears to be inversely related to the degree of physical effort required. As Figure 6 shows the length of time that can be tolerated at different temperature levels decreases as the amount of energy expenditure increases.

These results pose some interesting questions with regard to spaceflight. It is evident that craft temperature must be maintained at comfortable levels in order to ensure optimal performance. In at least one instance, temperatures rose above this level during Skylab 2 before the thermal screens could be erected to shield the exposed skin of the orbital workshop. Had the loss of the micrometeroid shield occured during the flight, exposure to the huge temperature increases could have had hazardous effects upon the crew's health and general performance efficiency.

One instance in which acreased temperatures posed problems for optimal crew performance included the shortening of some Gemini EVA due to increased thermal stress. As indicated earlier, metabolism rates increased dramatically during these EVA and the space suits provided were not able to fully compensate these changes. While later efforts during the Apollo and Skylab Programs seemed to have rectified this problem, the earlier difficulties do serve to emphasize

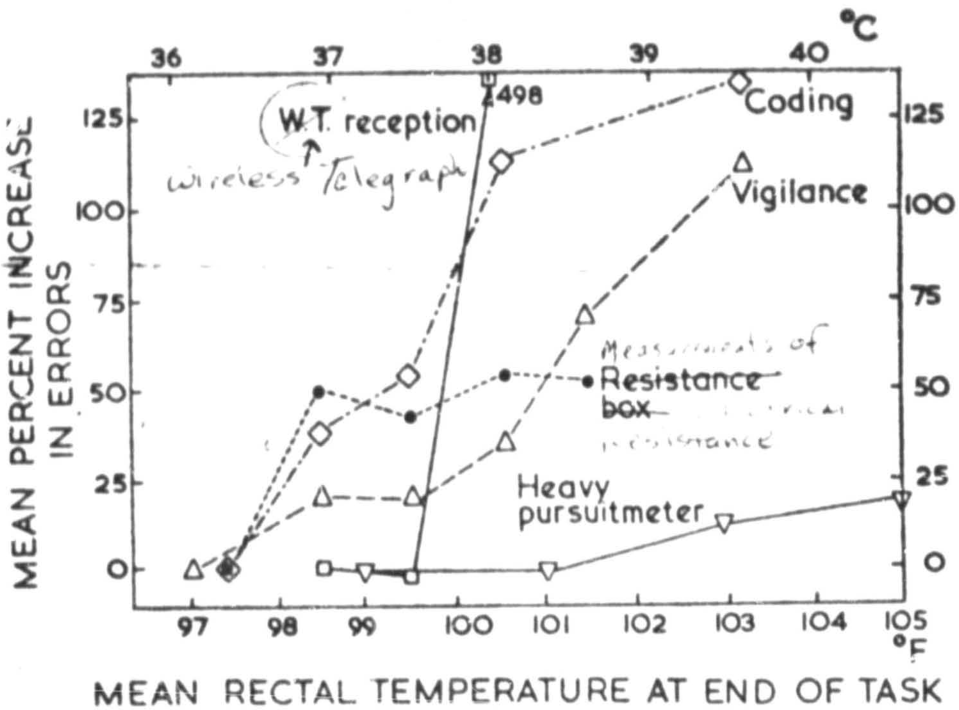

FIGURE 38. The average percentage increase in error when working in a hot climate, plotted according to the average superficia rectal temperature at the end of the working spell. A normal temperature would have been about 97.5°F (36.5°C). In the wireless telegraphy reception task, 11 experienced operators received messages in Morse code. The messages consisted of groups of letters and numbers. They were presented at a rate of 80 symbols per minute. In the coding task, 12 young enlisted men selected pieces of wood from a tray. The pieces had to be placed on wooden pegs in the correct order. They had to be the correct side up, and the correct way round. This was specified by a code typed on a slip of paper.

The resistance box task was performed by 16 young enlisted men. They had to identify each of 10 terminals with the outputs shown on a circuit diagram. This required taking measurements between pairs of terminals. The vigilance task is the clock test described in the caption of Figure 15, page 74. The results are from 89 young enlisted men. The heavy pursuitmeter task is illustrated in Figure 33, page 128. The 10 young enlisted men had to raise and lower a lever carrying a load weighing 50 pounds. (*After* Mackworth, N.H.: Research on the measurement of human performance. On Sinaiko, H.W. (Ed.): *Selected Papers on Human Factors in the Design and Use of Control Systems*. New York: Dover, 1961, pp. 174–331.)

ture was recorded automatically using a thermister placed under the tongue. It was raised rapidly by exposing the nude body to air moving 500 feet per minute with a temperature of 110°F (43°C) and 100 per cent humidity. Once raised, the body temperature was maintained by placing the man in an airtight suit which enveloped him up to the neck. The suit was ventilated with

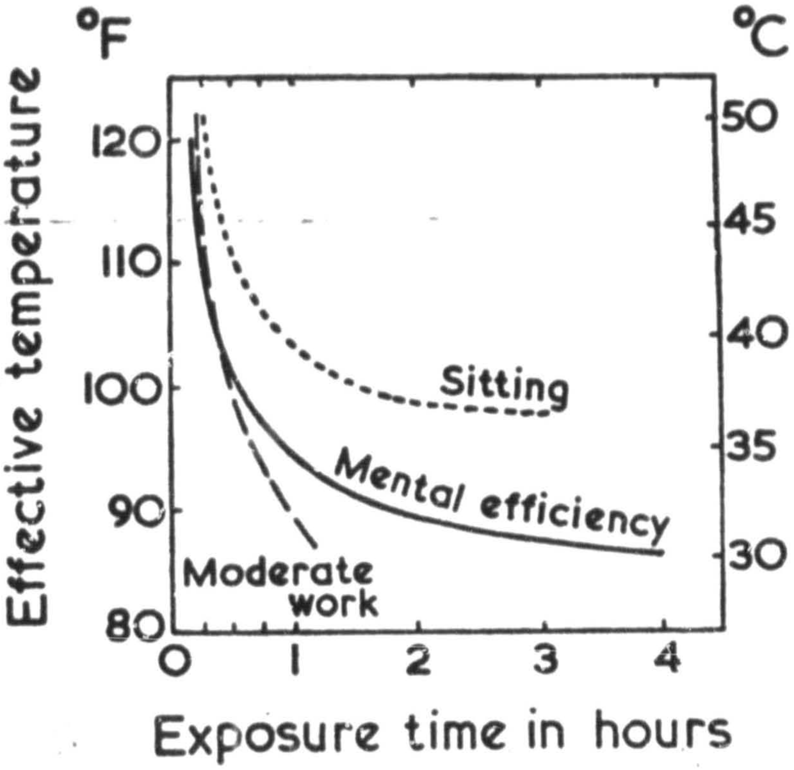

FIGURE 40. Critical combinations of effective temperature and exposure time. The upper dotted curve shows the mean physiological limit for sitting still. The lower broken curve shows the mean physiological limit for doing a moderate amount of work. Most people cannot tolerate longer exposures than those shown. (Results given by Lind, 1967, Figure 1.) The middle unbroken curve shows the limit for efficient performance. Points on or above the line have produced reliable drops in efficiency. (*After* Wing, J.F.: Upper thermal tolerance limits for unimpaired mental performance. *Aerospace Med.*, 1965, *36*, 960–964, Figure 2.)

(see Chapter 3). Probably the results used by Wing fit together so neatly because all the tasks were about equally insensitive to small increases in body temperature.

The 5-choice task was performed in air with a temperature of 100°F (38°C). The wet-bulb temperature was 90°F (32°C). The air moved at a rate of 100 feet per minute, and the men only wore shorts. The number of errors increased reliably in the heat. So did the number of response times longer than 1.5 seconds. Both effects were present during the first 5 minutes on the task (Pepler, 1959). The results are listed in Table 9, page 290.

Other Effects of Heat

As the temperature of the body rises, more blood goes to the skin to be

the point that heat can and does pose a potential obstacle to sustained performance during spaceflight. Just as increases in temperature can affect performance changes under spaceflight conditions, decreases in temperature can also produce efficiency decrements. Skilled motor performance shows progressive declines with continued cold exposure. Tasks requiring manual dexterity, tactual sensitivity, or rapid reaction times appear to suffer the most. For example, Dusek (93) tested subjects under several lowered temperature conditions and found decrements on several tests of dexterity and manipulativeness. Teichner (94) found similar results investigating windchill levels on tactual sensitivity, visual reaction time, as well as manual skill. These results are displayed in Figure 7.

While skin temperature of the hands would seem to be the obvious factor of importance here, it is important to note that other factors of a psychological or physiological nature also appear to be involved. Lockhart (95) investigated the effects of a cold body with or without cold hands upon three manipulative tasks: stringing blocks together, packing them into a box, or tieing a number of standard knots in a number of pieces of string. All three tasks were performed less effectively when both body and hands were cold. Warming the hands improved performance on all three tasks, but did not raise the levels up to control levels in the case of the two block tasks. This suggests that a possible change in arousal level could have influenced performance independently of limitations imposed by reduced digital capabilities.

These results indicate the importance of ensuring a comfortable temperature range for space crews. Some problem with lowered temperatures have been encountered in previous flights. For example, crew comments during several of the Apollo flights indicated that the

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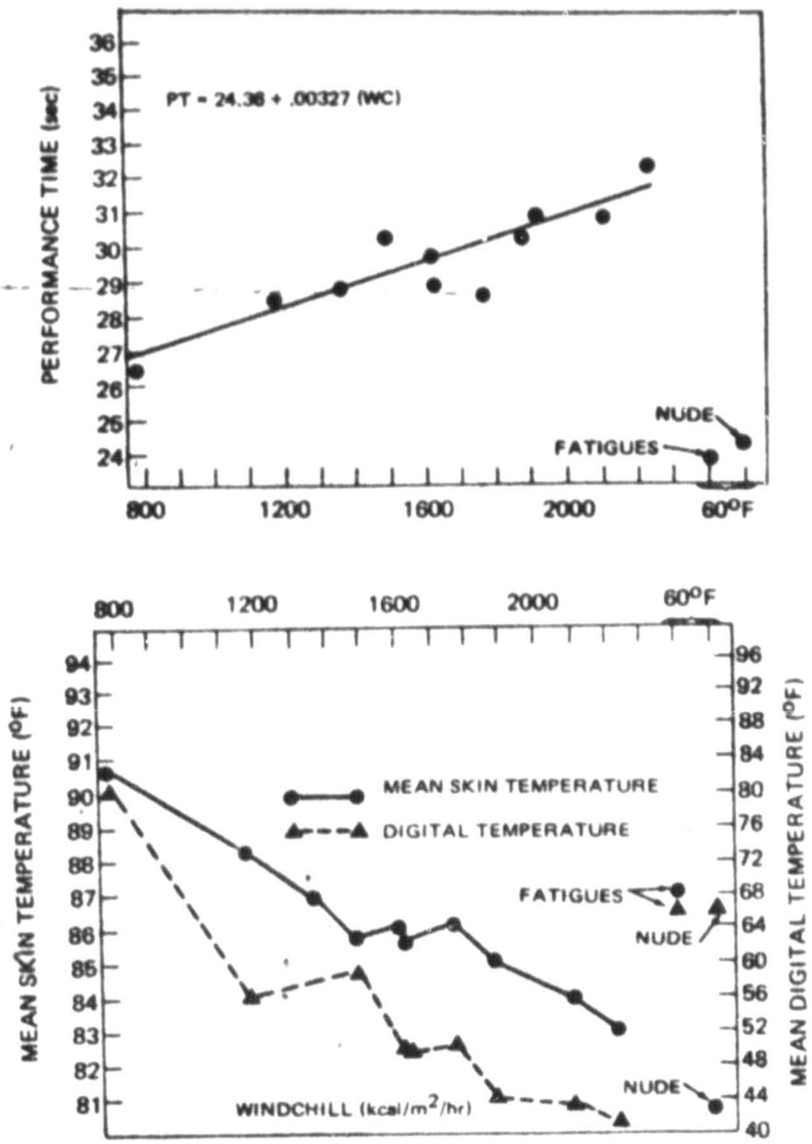

Figure 3–36. Performance time, skin, and digit temperature as a function of windchill; arctic clothing worn except where indicated. Hand exposed during performance only; follows approximately 35 min of exposure. (After Teichner, 1957; copyright 1957 by the American Psychological Association and reprinted with their permission)

Acclimatization to Cold

Recent evidence indicates that under cold conditions, increased voluntary caloric intake and other compensatory processes result from the increased energy expenditures associated with field activities (Davis, 1963) instead of from the low temperature as such.

Command Module was uncomfortably cool. During the Apollo 13 mission low electrical power levels reduced the cabin temperature to a range of 49° to 55°F. During the Apollo 11 mission, crewmen could not sleep in the Lunar Module because they were too cool. While these have been relatively minor problems, such fluctuations in temperature should not be discounted in considering all of the factors which may affect optimal performance during sustained space travel.

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Isolation and confinement. While these two factors of extended space flight are certainly immensely important issues, it is rather difficult to precisely detail what effects they will have on performance if indeed they do become problems. Many laboratory (96, 97, 98) and field research (99, 100) studies of isolated or confined subjects do report decrements in performance. Indeed the range of variables which are reportedly affected seem to be large. They include a range from simple retardation of motor coordination to an inability to maintain adequate cognitive functioning.

However, our understanding of how isolation and confinement affects performance is not as well detailed. One of the single most important factors seems to be changes in motivation. When arousal level becomes too low, as is potentially possible in these cases, subject apathy increases and performance decrements may become pronounced. Since this topic is covered in much more detail, let us suffice here to say that the effects of isolation and confinement can be widespread and pronounced, one effect being to reduce performance efficiency. At present this has certainly not been a problem during space missions. Flights have been of relatively short duration and crews have had more of a problem with work overload than underload.

However, as mission length increases and relatively easy return access to earth decreases, these may become more important topics. It will be necessary to provide more elaborate monitoring techniques to assess such factors as motivation and in turn to assess if and how performance suffers. This will be a particularly important point during long cruise phases or in permanent orbital stations where activities, social contacts, and volumetric area may be substantially reduced.

Summary of Habitability Factors

While the habitability issues presented represent only a portion of all the potentially important topics related to space craft environment and performance, they are certainly the ones which have received the most attention. The reader is referred to the habitability chapter for a more comprehensive treatment of this topic.

While most of the factors discussed have not posed any real problems during previously conducted missions they are of great importance to the planning of future missions. Designers and planners are going to have to become increasingly more sensitive to these human factors for the purposes of future extended spaceflight. The emphasis must shift from how to integrate the human into the overall system to how to fit the system to the overall demands of the human. Such a shift in orientation will be a challenge but is necessary to ensure sustained performance for crews already subjected to a myriad of adverse environmental conditions. Designing the craft to ensure optimal habitability must be a primary goal for future missions. This is true from the standpoint of optimizing performance as well as maintaining the health and safety of the crew. Factors such as noise, vibration, temperature, volumetric area, and social contact are just a few of the issues which must be resolved to enhance the probability of mission success. While our knowledge of these conditions during

short-term flight has increased, the longer time element and the added complexity of crew composition and task requirements dictate the need for extensive research along the lines of these topics.

Work Schedule Factors

In assessing the conditions pertinent to the optimalization of sustained complex performance several issues must be considered with regard to the amount and scheduling of work activities. Previous sections have discussed the conditions under which work is performed. Now the focus will shift to the duration and pattern of work and it's complement: rest and sleep.

Work-rest cycles. Variations in the work-rest cycle have been extensively studied because of their significance to sustained performance and safety (101, 102, 103). Several recommendations can be made regarding the scheduling of these cycles for long-term flights. First, operator efficiency is highest when a stable 24-hour period of work and rest is maintained. Other variations on the length of the cycle have not proven as efficient, or at the least require several weeks of adaptation. For example, Kleitman (104, 105) found that men could perform satisfactorily under 18 and 28 hour days, but that the time to adaptation was greater than 9 weeks. Furthermore, Brindley (106) was unable to find adaptation to a 22-hour day after 8 weeks. These results and others strongly prescribe a 24-hour day. Within this cycle, the critical issue appears to be the establishment of a consistent time for sleep. The time of sleep has implications for desynchronosis which can affect performance. Sleep schedules may also affect the quality, quantity, and patterning of sleep if drastic

alterations are made. Using the sleep phase of the 24-hour cycle as our anchor, several points can be made regarding the allocation of time for productive work on the one hand, and housekeeping chores, personal hygiene, and rest on the other. An initial point involves the type of productive work to be accomplished. Studies indicate that the type of work to be accomplished seems to dictate the most efficient duty schedule. For example, Chiles and Adams (1 3) research support the following conclusions regarding duration of work periods:

1) A maximum duty period of 4 hours is most efficient when a passive task is combined with one or more active tasks, the workload is not too great, and a high level of performance must be maintained.

2) A maximum duty period of 2 hours is advisable when a passive task occurs by itself. In this case attention cannot be adequately sustained to ensure satisfactory performance for periods longer than a maximum of 2 hours.

3) When there is a considerable variety in the major tasks, they call for active participation, or are passive tasks which have very readily detectable signals to which the operator must respond, the duty period may be routinely extended to 10 hours.

Each of these recommendations will no doubt have relevance to various phases of extended missions. It will be necessary to develop a taxonomy of tasks versus duty hours as they apply to each crew person at different points during the flight.

One potential difficulty involved in scheduling duty hours pertains to tasks which require continous monitoring or adjustments. It

will probably be necessary to have some form of crew duty rotation during extended missions. This poses the problem that to maintain maximum operation on a 24-hour schedule, some crew members will be working while others sleep. Here we face the problem of subgroup schisms. When cliques begin to form around individuals on duty dimultaneously, there is always the potential danger due to decreased communication that the desires and goals of the groups will slowly diverge, leading to inter-group hostilities. One possible solution to this is a planned intra-group rotation of all members on board. For example, members of one work period could be routinely shifted to the other duty period on a shared adaptation schedule. The established crew member would be on duty simultaneously with the newly shifted individual until their circadian rhythmicity adjusted. Then the former crew member would be free to shift to the other schedule (again shared with someone already adjusted to that sleep-work cycle). Such a procedure would be better in that it insures overall group cohesion and minimizes the formation of subgroups. This does pose the difficulty of desynchronosis, but if the duty shifts were conducted at appropriate intervals, adequate time to adapt would be available while an already established crew member was present to supervise and ensure that work quality was maintained.

Workload. As implied by the recommendations of Chiles, different tasks exert varying degrees of load upon an operator, whether physical or mental. This issue is important because the degree and duration of workload has many implications for the safety and efficiency of flight crews. As indicated by the air pilot literature, the association between workload and safety is indisputable. There have been many instances in which abnormal flight deck workload levels have been

implicated as causative factors in aircraft accidents (107). This is true both for overload and underload situations.

An understanding of the concept and measurement of workload in space will be a necessity for successful long-duration missions. While it is relatively easy to quantify the degree of physical exertion required by a given task, however all the quantification of mental workload still remains to be adaquately detailed. Simply defining this concept has been an effort in and of itself. Most definitions have coincided with the type of measurement used to assess the effects of varying degrees of load. Thus, there is a certain circularity in definition/measurement. Cohen and Silverman (1[illegible]) point out that measurement of mental effort might include "..... evaluating the peripheral, integrative, and motoric abilities of the operator, as well as emotional, physiologic, and hormonal responses."

Several approaches have been used in attempts to measure this aspect of the operator's requirements. All generally rely upon experimental evidence which indicates that humans have only a single channel cpability for processing information and making decisions. Based on this hypothesis is the idea of a maximum capacity for mental processing which, if exceeded by the demands of the tasks, yield overload and performance deterioration.

We can arbitrarily categorize most measurement attempts as subjective, objective, or physiological. Subjective measurements including the use of questionnaires and rating scales are currently probably the best single measure of short-term workload. Objective methods have relied upon laboratory tasks, similar to those described in an earlier section of this chapter, to investigate processing and decision making capabilities under a variety of loads and conditions.

Here the use of a primary and secondary task condition has been emphasized based on the single channel processing assumption.

Physiological measures have been based on neurological arousal and its established relationship with performance (several of these techniques will be discussed in a later section on stress).

Generally, there is an optimal workload which can be estimated for given tasks, individuals and conditions using this range of assessment approaches. Defining the workload requirements of space crews at each mission phase will be necessary prior to flight. Such investigations will probably involve several of the measurement approaches along the face validity dimension previously discussed. While this is a basic requirement to ensure crew safety and efficiency current knowledge still involves post-hoc rather than predictive propositions. Detailed and extensive research into this issue of workload, particularly mental, is still very much a necessity.

Desynchronosis. As indicated in discussion of work-rest cycles, a 24-hour day has been shown to be superior in reinforcing performance efficiency. This is most intimately tied to the notion of circadian rhythms. It is well documented that many functions of the human body are regulated on a near 24-hour basis (109, 110). Alterations in the time of sleep or work, both within and across these 24-hour blocks can have potentially detrimental effects upon operator performance. This disruption, desynchronosis, as evidenced in travelers flying across several time zones, produces symptoms which include malaise, insomnia, appetite loss, nervous stress, and inability to work (111, 112, 113). Coincident with this is a deficit in performance. Laboratory and field studies demonstrate that drastic phase shifts have frequently been associated with decreased reaction time, lowered attention, de-

crements in problem solving ability and a range of other psycho-motor and cognitive factors. Clearly, there is a danger involved in altering the sleep-wake cycle with regard to sustained performance. There have been some problems associated with these phase shifts during several manned space flights. Prior to the Apollo 9 mission it was common practice to employ staggered sleep schedules for crew members. This resulted in shifts of as much as 6 to 10 hours in the normal earth based time during which sleep would normally occur. Such description in the normal cycle was described as producing "a most unsatisfactory situation in flight" (114). Even during later flights where crew members slept simultaneously, the often hectic schedules required displacement of the sleep phase by several hours. These data suggest that a potential for performance decrements does exist when the normal circadian cycle is altered. For future extended missions the problems of adjusting schedules to work requirements will be an issue of concern. Future research in this area should be continued with emphasis on enhancing tolerance and minimizing problems through selection, pharmaceutical agents, adequate scheduling, etc. Some of these suggestions will be discussed in the Selection and Training chapter. For example, different personality characteristics seem to lend themselves to greater adaptation to phase shifts.

Another important issue of the area of circadian periodicity concerns the daily fluctuations in performance levels which have been reported for different tasks. It appears that performance may be subject to the same cyclic regulation as are many physiological functions. Varying levels of performance accuracy has implications for operators in space and should be considered. For example, performance as represented by the average number of simple addition sums completed in a 48 minute period is not a constant function

across a 24-hour time block, but rather follows a cyclic pattern coincident with diurnal changes in body temperature (115). Similar patterns have been observed for auditory vigilance tasks where both the average number of signals detected and the average response time were measured. Many other examples abound. Perhaps more important to the current discussion are findings related to the rhythmicity of performance levels just within the work day portion of the 24-hour cycle. Kleitman (104) regarded as a leading authority in this area, has concluded that there is a recognizable general pattern in the fluctuations of performance levels throughout the waking day which in many cases can be related to diurnal variations in body temperatures. His results indicate that performance on many tasks show a morning rise with a peak somewhere in the afternoon, followed by a fall. While the exact timing of these points is disputed by various investigators (116), all appear to agree that there is a recognizable general pattern in the fluctuations of performance levels during the working day. This poses some important research questions for space mission planners seeking to optimize work output and accuracy. Research should be devoted to assessing how various duty tasks should be distributed across the work day to mazimize performance. For example, it may prove advantageous to schedule delicate and sensitive tasks during the "morning rise" in body temperature and performance levels, and relegate less demanding or critical tasks for the "afternoon fall" period. Such a schedule would require constructing a taxonomy of tasks most appropriate for different phases during the daily work schedule, which in turn requires a greater understanding of what types and requirements of tasks are most affected by circadian periodicity than is currently available.

One factor related to circadian rhythmicity which has been extensively studied is the determination of variables which serve to regulate the 24-hour clock. These variables are referred to as Zeitgebers and consist of a wide range of physical, temporal and social "cues" which serve to entrain sleep and wakefulness to a particular rhythm. When Zeitgebers are not present, certain rhythms become "free running" and may vary from a 24-hour schedule as a result. This points out the importance of determining what specific Zeitgebers may be involved with what specific rhythms if we are going to attempt to artificially reproduce earth based Zeitgebers under space flight conditions. Given that few if any "natural" Zeitgebers will be available in space (e. g. sunrise-sunset) research is needed to determine which factors to provide and how to do it. Artificial lighting will be important. It may prove useful to experiment with automatic timed dimmers which can more accurately simulate daily earth lighting conditions. Also, social cues revolving around daily meals, work-rest periods, and evening leisure activities will become increasingly important. Indeed, some research indicates that social cues may be even more important than lighting conditions (117) for regulating work performance. Given that circadian rhythms and the issues which surround it do have important implications for performance in space, the issue of how to entrain those rhythms to the most advantegeous schedule becomes an important, if not critical, research area.

Sleep. Implicit in the study of effective work-rest conditions for space flight is the need to define and investigate those factors related to sleep and how this in turn may affect performance during waking hours.

performance and what is the time required to reach normal waking levels of performance? Langdon and Hartman (127) investigated this problem by assessing performance (turning off lights at a desk console when the experimenter programmed them to flash on) upon awakening at midnight and between 3 and 4 a.m. There were results which indicated it takes not less than seven minutes after being awakened at night for a person to achieve normal efficiency at this kind of task. Similar findings for reaction time are reported by Webb and Agnew (128) who awoke subjects during the deepest stage of sleep, stage 4. These results suggest that performance may be poor if a crew member is awakened during sleep to attend to an emergency. If a critical maneuver must be performed during the first seven minutes upon awakening, their performance may be incapacitated. While this fact has not been a problem to date, this does point to the advantage of rotating, 24-hour schedules which provide for some crew members to be on duty at all times.

Summary of Work Schedule Factors

The amount, type, and patterning of work activities will most definitely have a profound impact on the performance level of future space crews. Research is needed to define the scheduling of particular flight activities coincident with optimal arousal due to circadian rhythm fluctuations. The length of work-rest cycles need to be examined with respect to the types of activities the crew will engage in from hour to hour. The issue of staggered, rotating crews is a research question of importance here as well. Better defining the workload of crew members will also be necessary to minimize over or underload leading to performance decrements. To be considered within the work-rest cycle is the issue of desynchronosis, how to prevent it

through the development of effective artificial Zeitgebers, and how to arrange the daily routine to best make use of highs and lows in the cycle. Further research will be needed to better understand the effects of weightlessness and other space flight condition on sleep, and how in turn the alteration in terrestrial sleep patterns may influence performance in space. Each of these separate issues can be approached through better habitability considerations, crew selection and training techniques, and various countermeasures. This is a broad area of tremendous importance that will require a great deal of integrative research, both in space and on earth, to pull together and better understand the individual and interactional effects of the several factors entailed in work and rest scheduling to sustain optimal performance.

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Stress:

Definition, Measurement, Issues

Previous sections of this chapter have dealt with some of the important factors which are known to adversely affect performance levels. While we have addressed these variables individually, they are perhaps more frequently discussed under the general rubric of stress and stressors. An important theoretical and empirical question is the issue of how these different factors operate to produce decrements in performance. If indeed there is a similar action on the psychophysiological functioning of the individual, then the task of detailing how these individual components alter behavior would be greatly reduced. This idea was originally popularized by Hans Selye (129) who proposed that different "stressors" tend to produce similar

physiological changes. Selye pointed out that allthough different disease syndromes have unique characteristics, they have many features in common which elicit a stereotyped reaction by the body (the General Adaptation Syndrome). Thus, Selye has observed that such diverse factors as cold, heat, X-rays, adrenalin, insulin, muscular exercise, etc. produce a non-specific effect resulting in autonomic excitability, adrenaline discharge, heart rate, muscle tone, ural blood content changes, and gastrointestinal ulceration. Adreno-cortical enlargement and hyperactivity are ordinarily observed in the countershock phase. These findings suggest that it might be possible to understand the general, non-specific effect of any "stressor" and its implications for behavior change and thereby reduce the need to study each and every condition which might produce these changes. However, this view is unfortunately too simplified as detailed in the sections which follow.

Problems of Definition

One of the greatest obstacles to the productive investigation and understanding of stress is definitional. Stress has been defined in at least three distinct ways as noted by Appley and Trumbull (130):

1) On the stimulus side, the term has been used to describe situations characterized as new, intense, rapidly changing, sudden or unexpected. Also, stimulus deficit, absence of expected stimulation, highly persistent stimulation, and fatigue-producing and boredom-producing settings have also been described as stressful, as have stimuli leading to cognitive misperception, stimuli susceptible to hallucination, and stimuli calling for conflicting responses.

2) On the response side, the presence of emotional activity

has been used post facto to define the existence of stress. This usually refers to any bodily response in excess of "normal or usual" states of anxiety, tension, and upset, or for that matter any behavior which deviates momentarily or over time from normative values for the individual in question or for an appropriate reference group. Indices used include such overt emotional responses as tremors, stuttering, exaggerated speech characteristics, and loss of sphincter control, or such performance shifts as perseverative behaviors, increased reaction time, erratic performance rates, malcoordination, error increase, and fatigue.

3) The existence of a stress state <u>within</u> the organism has alternatively been inferred from one or more of a number of partially correlated physiological indices (to be detailed later) which can be usefully distinguished from responses which are of the order of overt performance changes or observable symptoms of emotionality, such as those noted above.

The lack of consistency in defining stress needs further consideration. If it is to be a useful term in our investigation of how environmental conditions affect performance, considerable theoretical refinement must still be accomplished. Without a commonly accepted definition the problem of investigating the multitude of individual factors which can reduce performance efficiency is only replaced by the lack of comparability in the single study of the hypothetical construct, "stress".

Given the problems of simply defining what is meant by the global term stress, we are further confounded by its measurement. Several avenues have been investigated. Researchers typically seek to

develop a condition which produces stress (again a definitional problem) and a measure which indicates its presence. These measures can be organized into at least three broadly defined and frequently overlapping categories which we will denote as tests of emotional response, psychological assessment, and physiological indices. Each is discussed below.

Tests of emotional response. This category focuses on the measurement of personality and its relationship to varying environmental conditions. It is assumed that alterations in the subjective report or objective observations of the subject can be related to stress. Specific techniques include interviewing and direct observation, self-report, and the use of certain projective psychological instruments. For example, Funkenstein, King and Drolette (131) interviewed subjects following a stress inducing task (repeating a previously learned story while a feedback mechanism returned speech, after a delay, through earphones). Rating measurements of anger directed outward, anger directed inward, anxiety, etc. were shown to be highly reliable and significantly correlated with a battery of other psychological and physiological indices.

Questionnaires such as the Taylor Manifest Anxiety Scale, the Minnesota Multiphasic Personality Inventory and the Edwards Personal Preference Schedule have been used to gain subjects' self-reported stress ratings. While these are more indicators of internal pressures and conflicts rather than external environmental stressors that can be effectively used to judge the subject's overall mental health and response style to adverse conditions.

Projective tests involve the presentation of ambiguous, unstructured material to the subjects in an effort to assess unconscious motivations and drives. The Rorschach Inkblot Test and

the Thematic Apperception Test are perhaps the two most widely used tests of this type. Burch and Childers (132), Burns and Ziegler (133), and Walker and Atkinson (134) have used these instruments before and after stress to measure the style of response to different situations in a useful fashion.

These types of assessment have very distinct advantages and disadvantages for stress research. They are useful in predicting response style to differing environmental conditions and may tell us something what events are indeed stressful to the individual. However, they usually do not indicate the degree of effect. Furthermore, they are not entirely suited for actual use in space as they require time out from the normal workday schedule and are not suited to the measurement of response charges during the actual stressful event. They are perhaps best relegated to the selection and training of astronauts. Here they can be used to better assess an individual's capacity for stress and to delineate what events may indeed be stressful. It does not appear at present that these instruments will be of significant value during actual flights, but pre- and post-flight testing might prove worthwhile.

Psychological assessment. This category includes many of the specific types of tasks already detailed in one of the first sections of this chapter. Perceptual tests, motor tests, cognitive tests, and tests of attention have all been shown useful in assessing stress effects to varying degrees. The basic paradigm typcially involves measuring a response to a particular task before, during, and after stress, in various combinations, and determining whether responses have changed which can logically be attributed to the supposed stressor. While useful in ground based, highly controlled experiments, this approach has been of genuine value. Much of our current knowledge on the per-

formance effects of various environmental parameters has come from this type of work. However, in the more complicated world of actual space travel these types of indices become increasingly less useful for isolating what specific factors from a myriad of environmental influences produce what specific effects. The need to more adequately study the interaction of different stressors is an issue of paramount importance and will be detailed in the next major section.

Psychophysiological indices. By far the most appealing measures of stress for use in actual space flight are those included in this category. The more quantitative nature of these variables and the potential for minute to minute, or hour to hour measurements has much to offer to the study of stress in space. The physiological study of stress is based on and supported by at least three specific cornerstones. The first, originally proposed by Cannon (135) and later demonstrated by Ax (136), Elmadjian, Hope, and Larson (137), and others, holds that emergency reactions are mediated by actions of the sympathetic nervous system. Measures of activity of this system (adrenalin, noradrenalin) have commonly been used in stress research.

The work of Selye (138) provides the second concept. The General Adaptation Syndrome is mediated through the secretion of adreno-corticotrophic hormone (ACTH) by the pituitary gland which stimulates the adrenal cortex to produce and secrete steroid hormones producing changes including decreased lymphatic tissue and alterations in protein, carbohydrate, and fat metabolism. Thus, the measurement of adrenal hormones and their derivatives as well as changes in circulatory lymphocytes and other peripheral hormonal effects are a second area of indices often examined in stress research.

The third concept is based on measurement of activity in the

central nervous system. According to Magoun (139) and others the reticular formation receives information from collateral sensory tracts and sends impulses to the cortex which regulates arousal and alertness. The assumption being that an organism under stress is more highly aroused. This approach has lead to the measurement of brain waves, heart rate, skin resistance, blood pressure, and several other indices in efforts to measure the degree of psychophysiological arousal coincident with various stressors.

Nearly every major American space mission has analyzed some data pertinent to these three areas of approach. For example, urinary catecholamines, heart rate, and respiration rate were measured on the Gemini VII and IX missions as indicators of short and long-term stress. Brain wave patterns during sleep have been investigated during Gemini VII and Skylab. The use of psychophysiological techniques has been of great value in the study of stress in space, both in monitoring the existence of stress and in better understanding the mechanism. However, this approach in and of itself does have certain disadvantages. As Lacey and Lacey (140) point out, subjects tend to differ in their responsitivity on different measures of stress. Each individual seems to respond to stress with a "hierarchy of activation" demonstrating relatively overactive levels using certain physiological measures, average levels by other standards, and an actual underactivity using still others. Thus, no single measure can indicate the total arousal of the subject. Furthermore, even an extensive battery of measures may not be entirely useful in assessing a single aspect of the environment and its potential stress effects. Since the autonomic nervous system responds to the total complex environment the study of how a specific feature affects the individual is further clouded by their perception

of the situation and the concurrent anxiety. These limitations point out the need for continued integration of various stress measures: subjective report, psychological data, and psychophysiological data.

These problems also point out the potential danger of assuming the existence of a generalized state called stress. It should always be remembered that stress is a hypothetical construct and may not necessarily be representative of something that exists in reality. Researchers must always be aware that particular situations and environmental factors may not produce the same effects across all individuals or even consistently within an individual.

Voice analysis. One new index of stress that is in the development state is the use of auditory frequency spectrum analysis or more simply, voice analysis. The potential advantages of such a technique would be tremendous given that it is usually nonintrusive. In the majority of situations where we might be concerned about decrements in performance due to stress, some voice communication normally occurs. Therefore, it would not be necessary to add anything to the crew's tasks or workspace to perform voice analysis.

Presently the two most widely used detection devices have been marketed by Dektor Counterintelligence and Security, Inc. and by Hagoth Corporation. Originally this equipment was developed as an aid to police and detective work, but has been extended to broader areas of stress research more relevant to our current interests. For example, Older and Jenny (141) analyzed Skylab astronaut voice communications to determine situational stress. Values from this analysis were correlated with operational variables better known to represent varying degrees of stress. While they did find some

statistically significant relationships, they concluded that the technique is not yet valid enough to warrant use in missions in the immediate future. Russian scientists Siminov and Frolov (142) have performed similar tests with cosmonauts and report that substantial further work is required.

While the present voice analysis state of the art is still relatively primitive, this may well prove to be one of the rewarding techniques in the years to come. It is certainly an emerging area that deserves further consideration and one that space planners and researchers should support.

Interactional Problems in the Study of Stress

So far we have generally addressed the problem of stress and its effects upon performance by considering individual environmental factors in isolation. However, our greatest challenge in monitoring, predicting, and controlling the adverse performance effects of various spaceflight factors is to do so in a complex operational setting in which combined environmental stressors may have entirely different interactional effects. Unfortunately, relatively few laboratory studies have described the tolerance levels, phychophysiological effects, or performance alterations which result from sequential or simultaneous exposure to two environmental stressors. Fewer yet have tackled the research problem of three or more overlapping stressors. However, from the work of Broadbent and Dean, McGlothlen and Monroe (143, 144, 145), one general point does seem clear. One cannot necessarily predict the effect of combined stressors by simply adding their individual effects together. In addition to "additive" effects, combined stressors may have synergistic effects in which the sum of the combined stressors is actually greater than the effects of the in-

dividual factors alone. Such an effect has been reported by Mogel, Keating, and Stern (146) in their work on heat and vibration. When heat was investigated alone, the physiological parameter of rectal temperature increased proportionally. Vibration of up to 15g when studied alone tended to lower rectal temperature. However, when heat and vibration were combined, rectal temperature rose in proportion to degree of vibrational stress beyond the levels recorded for heat or vibration alone or according to an additive model. Combined stressors may also have antagonistic effects in which the effects of individual factors may oppose each other when combined to produce a total performance decrement that is less than predicted from an additive effect model. For example Clarke, Taub, Scherer, and Temple (147) found that +3.85 G_x acceleration improves the visual performance decrement associated with 11 Hz $\pm$ G_x vibration. Loss of sleep and noise provides an additional example. Wilkinson (148) found that sleep loss alone or increased noise level alone, both produced large and reliable increments in performance errors, when loss of sleep was combined with noise, the increase in the percentage of performance errors was smaller than with loss of sleep alone.

These results highlight our need for better information regarding the effects of combined environmental factors. Unfortunately, our current knowledge is greatly lacking. Continued research in this area could be useful in better predicting how spaceflight stressors may influence performance under operational conditions. Also, as our knowledge increases, it may be possible to produce beneficial combinations. If we are to better simulate and investigate the effects of long-term space travel on human performance, at some point our efforts will surely have to focus on how the total environment affects the individual. The study of combined environmental factors and their

interactions would certainly put us a step closer to this goal.

Summary of Stress Research and Concepts

The previous sections have shifted us away from the approach of investigatin individual stimuli (i. e., environmental factors) - response (i. e., performance alteration) units to a model more appropriately illustrated as stimulus-stress-response. The assumption is made that the use and study of "stress" may add something to our knowledge of how the environment (both external and internal to the individual) can influence performance beyond a simple study of stimulus-response units. Whether the use of this term and its associated implications is always the best approach is certainly a point of contention. While efforts to operationally define and measure this concept have led to contradictory results, the economy in theoretical terms seems great enough that its continued usage seems likely. One point to be discussed in the next section is closely related to the differences in models and applications suggested by stimulus-response theories and stimulus-stress-response models just mentioned. This is the notion that stress as a generalized phenomenon should be amenable to generalized training procedures. In other words, if a multitude of factors are known to produce the state of stress, then training procedures known to reduce stress due to one type of factor may be useful in reducing others. This is certainly an intriguing possibility and one that deserves discussion.

Countermeasures For Spaceflight Performance Decrements

This section will detail some potential measures which may be useful in minimizing the problems of spaceflight performance decrements

and optimizing the probability of sustained optimal performance levels. The emphasis is on new research areas or novel approaches to the question.

General Versus Specific Training Techniques

The question of general versus specific stress effects has tremendous implications for astronaut training procedures. Recently the relevant literature shows a trend away from the generality or nonspecificity notion of stress portrayed by Selye (129, 130) and Miller (149) with major advances made through the recognition of the specificity of stress. Lazarus, Korchin, Schafer (150, 151, 152, 153). This implies that the most effective training procedures may be those that concentrate on specific environmental events and how to individually (and in combination) reduce their adverse effects upon performance. While more detailed discussion of selection and training procedures is available in a separate chapter, let us mention a few specific factors in this section which more or less directly relate to the maintenance of optimal performance levels.

Motivation

Probably the single greatest variable in determining performance under a variety of conditions is motivation. There are apparently large numbers of potential hazards to effective performance in space (space sickness, isolation and confinement, noise, weightlessness, etc.) which crews to date have been able to tolerate and minimize largely due to their high motivation levels and desire to accomplish mission goals. To extend this asset to more long-term, perhaps mundane, missions in space is truly a challenge. Assessing ways to enhance or maintain morale, dedication, and individual motivation for long periods may be one of our greatest obstacles and certainly one of our greatest aids if accomplished. Based on field research in the Arctic and Ant-

arctic, in submarines, and in experimental isolation projects we know that subject compatibility, significant and novel work, as well as inter- and intra-subject personality components are intimately involved in this issue. While further discussion of this topic is reserved for other chapters, suffice it to say that effective performance is often contingent upon effective motivation, particularly in circumstances where a variety of environmental factors have the potential for adversely affecting performance.

Hypnosis

As a countermeasure to various conditions which may jeopardize sustained quality performance, the use of hypnosis is an often mentioned, but little researched phenomenon.

Hypnosis has been investigated within the confines of stress research with often startling results. For example, Orne (154) and others have demonstrated evidence that hypnosis can be effectively used to eliminate the normal physiological changes which accompany the anticipation of dreaded events. Through the suggestion that a real danger is not one, that there is no threat when there is one, you can change the response of the system even when damage is in fact induced (155). While such a technique would need to be used judiciously, there are certainly occasions in which reduced fear and arousal might prove extremely valuable to the completion of a task during a crucial or overtly dangerous phase of the mission. Hypnosis could conceivable used to implant ideas for reducing fear and anxiety involving unknown situations or in directing attention to specific tasks to be performed under stress.

There is some empirical evidence (156) to suggest that hypnosis might also be valuable in training individuals to induce self-hypnosis so that they may bring about sleep when desired and awaken at any time

in an alert condition. This would have rather definite advantages over the use of drugs which may produce unwarranted physiological side effects or residual effects upon performance.

Hypnosis could potentially enhance astronaut training procedures through the creation of "realism" in simulators. As Dorcas (156) points out "subjects have been induced to perform asocial and dangerous acts, such as placing their hand in a container of supposedly poisonous reptiles or attacking their superior officer who, they were told, was an enemy agent." If hypnosis can produce such "illusions", it is not implausible that it could be used to persuade subjects that mock-up simulators were at least partially real. This could aid in the development of better performance assessment techniques (given the greater generalizability to actual operational conditions) and to better selection of astronaut candidates (given the opportunity to evaluate them under more "realistic" conditions).

Negative Ion Concentrations

Many claims have recently been made that increasing concentrations of negative ions in air supplies can increase alertness and therefore overall performance. Likewise, it has been stated that higher concentrations of positive ions can reduce alertness and retard performance. If and how this is accomplished is at present unknown. While there have been reports which demonstrate statistically superior performance during exposure to elevated negative ion concentrations, these results seem suspect at best, given the rather unsophisticated nature of the experiments and the lack of control over a multitude of confounding extraneous variables (157). Likewise, there are as many, if not more, negative results which add to the conflict. For example Barron and Dreher (158) tested Lockheed pilots under varying ion concentrations,

but found no significant effects when measures of brightness discrimination, reaction time, card sorting and muscular steadiness as well as physiological and biochemical indices were used.

It is not our intention to support or deny any claims regarding the effects of ion concentration, but merely to point out that this is an area where further research is needed. If in fact superior effects can be produced using elevated negative ion concentrations such a finding could be of potential value to space crew operators performing a variety of repetitious tasks. It seems reasonable to state that while this is a highly controversial topic, it is an area that should be further explored to better clarify if verifiable benefits can be obtained and whether such effects have any potential relevancy to the requirements for sustained high quality performance during long-term space mission.

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